

Design and Simulation of Two-Phase Hybrid Stepper Motor with Current Tracking

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Abstract - In motion control system, stepper motors are widely used in robotics and numerical machine tools, where the high-precision positioning is required. Precise control of stepper motor is always been a challenging because of non-linear nature of the motor dynamic. Using discrete pulse in full stepping and half-stepping mode and generate the speed profile of the stepper motor with MATLAB Simulink. Simulation had done with the controlling current by bang-bang control, which is continuously maintain the current in to its sustain limit in the phase and provide the desire speed and position of the motor and express the reasonable capability of the motor.

Keywords — Bang-bang control, Full or half stepping, Hysteresis control, Speed of motor, stepper motor.

I. INTRODUCTION

Stepper motor are used in positioning applications due to their durability, high efficiency.[1] Reluctance motors have attracted much attention over the past few years due to their simplicity of construction and low cost. Compared to dc motors, variable reluctance (VR) motors have advantages such as no mechanical brushes and no permanent magnets either on the rotor or on the stator. However, the drawbacks are complex drive electronics and nonlinear torque-current characteristics. These problems are being addressed in recent advances in power electronics and control [2]. Hybrid stepper motor is preferred because of small step angle. Its applications include position control of solar array antenna and robotics, etc. The stepping rate normally follows the excitation rate. However, due to the mechanical constructions, resonance and instability are noted at certain speeds. The behavior of the machine varies with loading condition and needs to be address. The possibility of simple excitation schemes like full and half-stepping modes that can be generated with simple digital devices is another major attraction for use of stepper motors. High frequency operation can achieved easily with these excitation schemes[1]. The mode of operations limited with medium frequency range that depends on the required precision of position and speed of the motor. For Prediction of the speed resonance occur which is determined by rotor inertia and stiffness[1]. Resonance of motor identified with two-way mechanical or electrical parameters. Mechanical parameters consider the rotor position, speed, torque and vibration.

Electrical parameters include the phase current and back Electromotive Force (emf).

In hybrid step motor have permanent magnet in rotor permanent magnet suffer with problem of torque ripple. Voltage excitation in phase will eliminate or reduce the problem of torque ripple. For voltage excitation, Phase current is important parameter for measurement and the rotor position is also takes and important role for this technique. Torque ripple in electric motors can be reduced either by design or by control. The desirable detent torque of step motors (which provides passive braking in the absence of power) is also reducing when a step motor is designed for small torque ripple. Hence, the reduction of torque ripple through control is an attractive option leading to better overall performance. Interest in torque-ripple reduction in the control community is fairly recent [5].

Normally, The Position of rotor measured with the encoder or hall sensor. In order to control the position and speed of HSM need to control stator current. The quality controls of these methods depend upon the quality of the waveform. Good current waveform depends upon the switching frequency of PWM, modulation index and the shape of current or voltage wave forms. The control method in inverter is voltage control or current control. The current control is preferable due to simple. It has advantage in eliminating stator dynamics in high performance drive systems. There many methods of current control such as: linear and non-linear current controllers. Linear controller includes PI controller, state feed-back controller and predictive current controller. Nonlinear controller includes bang-bang controllers (Hysteresis control, ramp type control and delta modulator) and predictive controllers with online-optimization [12]. HCC technique offers simple control, fast dynamic response, increased reliability of semiconductor switch due to less current stresses, and simple closed-loop control [13]. hysteresis current control is used due to fast dynamic response and doesn't require any information about the system parameters but this technique has suffered from some disadvantage as, switching frequency of inverter varies within a band because peak - to - peak current ripple is required to be controlled at all points of the fundamental frequency wave [12]. Variable switching frequency has been recognized as solution for motor drive systems to minimize mechanical noise but it is not recommended for power system applications

which affect the quality of the power system. Many methods are suggested adjustable speed drives by adapting the hysteresis current controller as in the hysteresis band is programmed as a function of load current drive system.

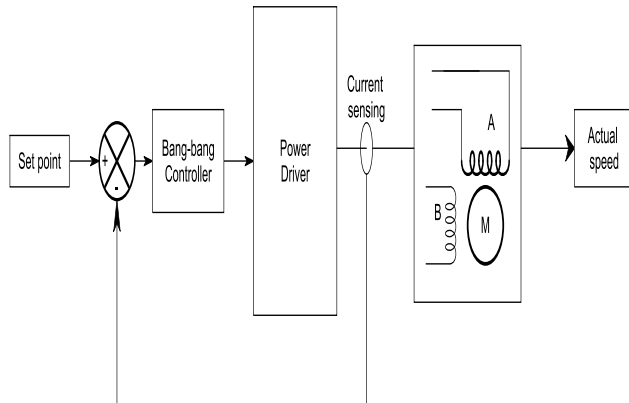


Fig. 1 Block diagram of stepper motor control with bang- bang control

This paper presents an original PWM for stepping motors, based on current feedback (Fig.1) that allows high performances and low vibrations without losing efficiency and allows achieving dynamic performances more precise without losing stepping motor advantages such as position control accuracy and reduced size and cost.

A drive was designed and realized the control technique with a small stepping and reasonable speed of motor.

Section II Introduce the simple mathematical model of the hybrid stepper motor; Section III report the brief over view of full stepping and half stepping driver. Section IV reviewed the Controller for driver to control the current Section V report the simulation result for Different driver configuration and finally, section VI concludes the paper with some remarks.

II. MATHEMATICAL MODEL OF STEPPER MOTOR

A. Mathematical model of HSM

The various stepper motor is available for research. In hybrid stepper motor have permanent magnet in rotor which is toothed magnetic structure and stator have also same structure, so permanent-magnet torque can be generated in rotor and reluctance torque in stator. The rotor of hybrid motor is composed with two semi rotors, which have opposite magnetic polarity and 180-degree phase displacement in teeth position. heoretically, the motor can be considered as a multi pole synchronous motor [3]. Mathematical model of hybrid stepper motor is to study the dynamic behavior of motor. Model consists of electrical dynamic of stator together with the shaft mechanical dynamics.

Electric response is much faster than the mechanical response, which allowed considering mathematical model only. Consider the mathematical model which is consider in paper [1],[6],[9], Model consist electrical and mechanical equations. The electrical equations are given by,

$$\frac{dI_a}{dt} = \frac{1}{L} (V_a - RI_a + Km\omega \sin(N\theta)) \dots \dots \dots (1)$$

$$\frac{dI_b}{dt} = \frac{1}{L} (V_b - RI_b + Km\omega \cos(N\theta)) \dots \dots \dots (2)$$

And mechanical equations are,

$$\frac{d\omega}{dt} = \frac{1}{J} [-KmI_a * \sin(N\theta) + KmI_a * \cos(N\theta) - B\omega - TL - Kd \sin(4Ns\theta)] \dots \dots \dots (3)$$

$$\frac{d\theta}{dt} = \omega \dots \dots \dots (4)$$

Where,

I_a and I_b are the currents in phases A and B respectively (Amp),
 V_a and V_b are the voltages on phases A and B respectively (Volt),

ω is the rotor speed (rad/sec),

θ is rotor position (rad),

R is the resistance of the phase winding (Ω),

L is the self-inductance of the phase winding (H).

K_m is the motor torque constant (Nm/A),

B is the viscous friction (Nms²/rad),

J is the rotor inertia (Kg.m²)

T_L is the load torque (Nm)

The detent torque is due to permanent magnet interacting with the magnetic material of stator pole. It is negligible, as its magnitude is less than holding torque. With respect to load Variation of J and B were negligible.

B. Over view of Driver of motor

Fig.1 shows the controlling of motor by controlling current in phase according to the mode of excitation and as per requirement of position and resolution. Mainly four type of excitation mode is defined through which motor was operated. Full step wave drive having any of the one phase is on at a time or in other words current passing only through one phase at a time. Fig.2a shows the wave drive current waveforms. Full step two phase on have excitation shown in Fig.2b which shows that at a time two phase on and current passing through both the winding. Half step excitation mode involves alternating single and dual phase operation and provides twice the resolution than full step mode, which increased smoothness at low speed. Voltage of driver was depends on torque requirement for desire speed.

Fig.2 shows the excitation mode for clockwise direction for counter clockwise rotation need to reverse the sequence of current in winding.

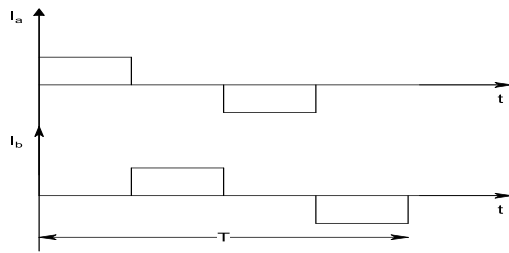


Fig. 2(a) Full step sequence of current in motor

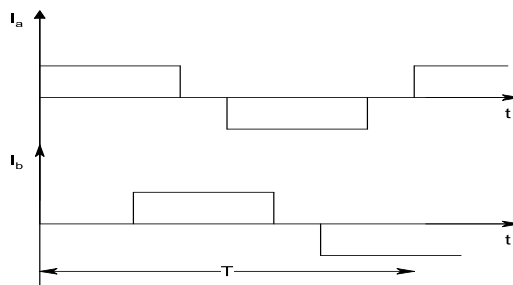


Fig. 2(b) Half step sequence of current in motor

C. Current control with Dual H-Bridge circuit

Stepper motors having various type of drive to obtain improved speed performance from a motor are constant current drive constant voltage driver.

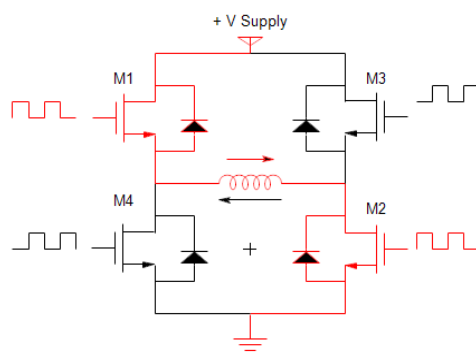


Fig. 3 H-Bridge Circuit

In this paper current control done with controlling the current in phase switching of current in different phase by H-bridge. It consists four switches which control the current in stator. Winding needs to be reverse in order to reverse a magnetic pole of the stator which is complicated

Therefore, H-bridge is use for two-phase hybrid motor. Two phase motor have two lead per phase so two H-bridge is use for motor.

The MOSFET switches use to built H-bridge. The switches M1 and M3 would never be close at the same time, as this would cause a short circuit on the input voltage source. The same applies to the switches M2 and M4. This condition is known as shoot-through. An H bridge is an electronic circuit that enables a voltage to be applied across a load in either

direction. When the switches M1 and M2 are closed (and M3 and M4 are open), a positive voltage will be applied across the motor. By opening M1 and M2 switches and closing M3 and M4 switches, this voltage is reverse, allowing reverse operation. Dual H bridge circuit use to control the phase current in both the phase.

III. CONTROL SCHEME OF HSM

In this work, the current control in motor winding by hysteresis current controller. It is used due to simplest design, fast dynamic response and insensitive to motor parameters. In this method each phase consists of comparator and hysteresis band. The gate pulses are generated due to error in the current and maintain current constant. The error comes from comparing between the reference current and actual current. The main task of this method of control is to force the input current to follow the reference current in each phase.

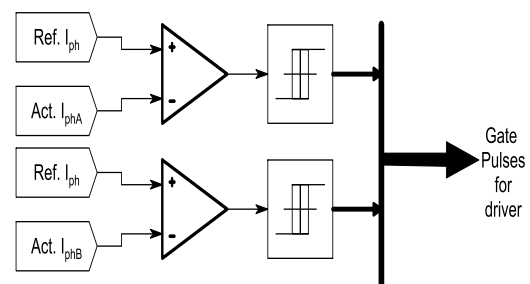


Fig.4 Hysteresis current controllers for producing gate pulses

In this method of control, the deviation of the current between the upper and lower in the hysteresis band is limited. In any phase, if the actual current becomes more than the upper limit than of hysteresis band upper arm of inverter is off and the lower arm is turn on so current decays when current goes below the lower limit than lower switch of and upper switch is on so current again rise in the phase and current maintain in the hysteresis band.

The current control in phase winding of the motor for controlling the motor, which consists of two hysteresis controllers or bang-bang controller, is built with MATLAB/Simulink blocks. The motor currents are provided by measurement and compared to the reference currents for both the phases. The current error is passed through hysteresis controller represented by relay block with fixed band in to produce the gate pulses as shown in Fig.2 that pulse fed to the motor according to configuration of the driver motor will operate in a either forward or reverse manner.

IV. SIMULATION AND RESULTS

In order to examine the feasibility of using Bang-bang controller with HSM, it is necessary to understand the methodology of designing this controller to control of speed and position. Using MATLAB environment achieve the speed and position with calculation of frequency with full stepping

or half stepping mode. . Here Driver operated at 24 volt dc and reference pulse is given to the controller. After designing the scheme of controller simulation result are observe.

A. MATLAB Simulink block

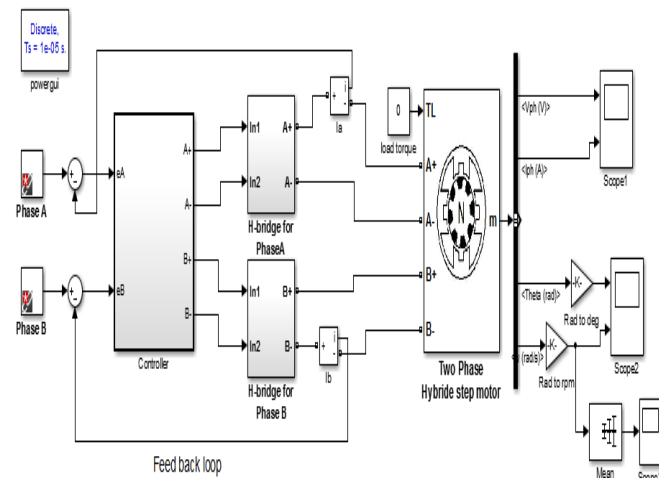


Fig. 5 MATLAB Simulation block of stepper motor

B. Simulation results

1) Full stepping mode

In full step mode the after the calculating the frequency define time period for the pulse rate on with motor can operate. In this mode the duty cycle of the pulse is 25%. According to the pulse require torque is generated and the current is passing through the winding as per the pattern of mode.

Fig.6 shows the winding current after the controller which is control in band of ± 0.1 with 4A current rating.

Time period for full step mode is calculated by, $T = \frac{0.3}{rpm}$.

Calculated T is only for 1 pulse, here two phase motor is use so it has for windings so the total time is 4T. As per the current passing through the both phase rotor rotates in clockwise direction which is shown in fig.7.it shows that motor give the pulsating speed of the motor. For the very first pulse motor will hold at the initial position so initial speed is zero when the step change accrues Motor give the high peak speed then when motor hold at that step speed remain zero or it oscillate across the zero.

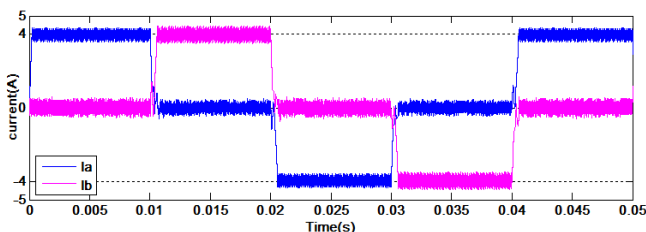


Fig. 6 Phase current diagram for full stepping mode

After taking the mean of speed output we see that motor will reach at require speed after some time period. It reaches

at desire speed within 6 to 7 step change of the motor. Here result obtain with same value of T for both the mode.

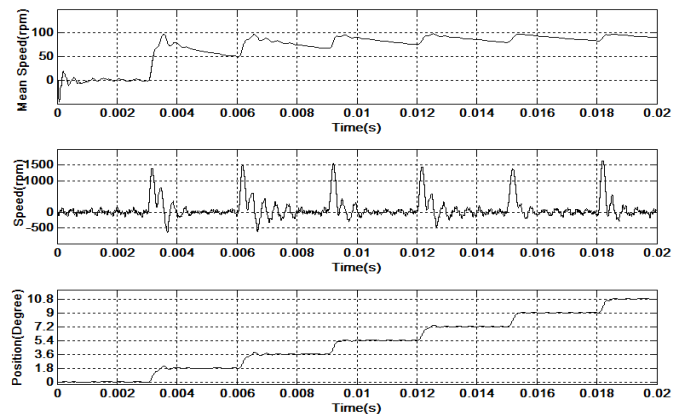


Fig. 7 Speed and position of motor with 100rpm speed

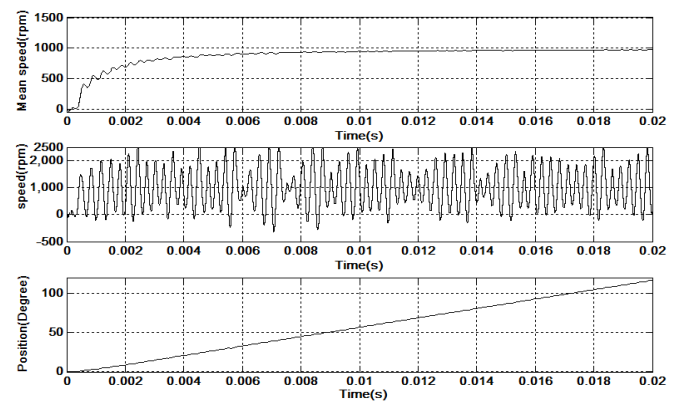


Fig. 8 Speed and position of motor with 1000rpm speed

Fig.8 shows the speed and position of stepper motor with 1000rpm speed .Speed of motor is oscillatory because the change of step is very fete. Performance of motor is same as fig.7 and 1000rpm speed achieve after very short period of time.

2) Half stepping mode

In half stepping mode the resolution of motor is double than the full stepping mode and the Time period for switching the current in the phase is half than the full stepping mode. Duty cycle of pulse is 37.5%.

At a same time 2phase excite with current passing through it so motor rotate in the resultant direction of the both forces witch act by the both phase.

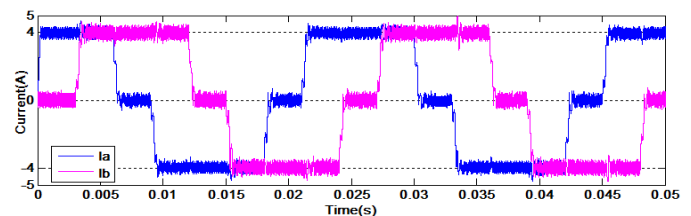


Fig. 9 Phase current diagram for half stepping mode

Fig. 9 shows the Winding current after the controller which is control in band of ± 0.1 with 4A current reference.

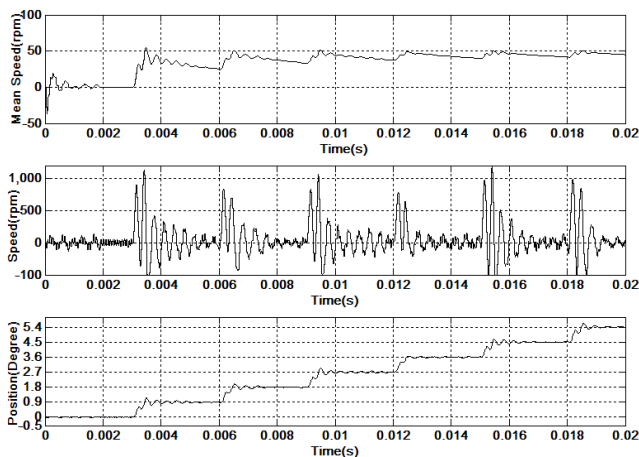


Fig. 10 Speed and position of motor with 50 rpm

Fig.10 shows the performance of the motor with half stepping mode with same T of 100rpm speed in full step mode. By comparing both the result clearly see that speed is half than full step mode. Here also the motor speed up when step change will accorded when motor is at holding position the speed is Zero for that time.

Fig. 11 gives the oscillatory response of speed because the step change is fast and motor reached at desire speed after small period of time.

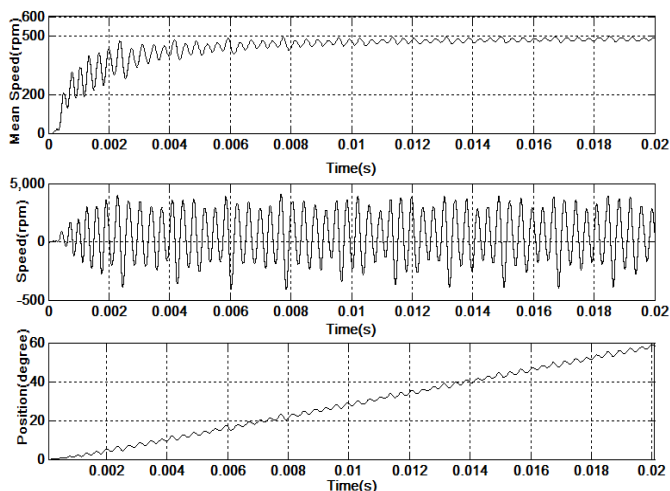


Fig. 11 Speed and position of motor with 500 rpm

V. CONCLUSION

In this paper, a bang-bang controller for a HSM has been presented. The HSM drive system examine by simulation and also the different modes of operation. By using hysteresis band maintain the current in a phase that give better and satisfactory performance of drive and motor. By controlling current which is continuously maintain the current in to its sustain limit in the phase and give the desire speed but

unfortunately this controller have limitation of fast switching so this controller not used for high speed or in the slewing range. For improving the performance go for the higher controlling technique.

VI. APPENDIX

A.Parameter of Hybrid Stepper Motor

Motor Parameters	Value
Winding Inductance	1.2 mH
Winding Resistance	0.4 Ω
Step Angle	1.8°
Maximum Flux Linkage	0.005 V·s
Maximum Detent torque	5.664 N·m
Total Friction	0.003 kg·m/s
Total Inertia	0.003692 kg·m ²
Phase Current	4.0 A
Hysteresis band	± 0.1

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